Black Holes and Prisoners: Understanding AS112 Deployment Characteristics

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Abstract. AS112 is a distributed, volunteer-run, anycast DNS service that acts as a sink for leaked DNS queries for local resources, preventing them from overloading core DNS infrastructure. AS112 helps protect important parts of the Internet infrastructure, but there has been no comprehensive study of who runs the AS112 servers, where they are located, and whether they effectively capture leaked queries. Using RIPE Atlas and 33646 open recursive resolvers, we detect 469 AS112 sites, run by 97 operators, and compare the response time and query distances of AS112 to root server queries. AS112 performs well, with 23.21% lower median response times and 36.11% lower median distances than the root. However, AS112 is largely dependent on few large operators (one operator serves 41.71% of probes in our study), limiting its resilience.

1 Introduction

Misconfigured hosts can leak DNS queries for local resources, such as reverse DNS queries for local addresses [6,39] and queries for the `home.arpa` [45] and `service.arpa` domains [35], into the public Internet. This is a concern because such queries place a burden on critical infrastructure (e.g., Cloudflare receives ∼100k of these requests per second [22]), and because they can leak private information about those local resources [14].

The AS112 project (https://www.as112.net) is a worldwide, distributed, volunteer-run effort to respond to such leaked DNS queries, diverting load from the `in-addr.arpa` [6] and `arpa` nameservers [35,45]. Anyone can run an AS112 server and respond to queries via anycast IP [6]. This lack of central governance facilitates wide deployment, but it is not clear who runs the AS112 servers, where they are located, from where they are accessed, and whether they effectively distribute the load. AS112 protects critical infrastructure, but we do not know how well it works, or how its unplanned, volunteer-led infrastructure compares to more carefully planned infrastructure deployments, such as the DNS root servers.

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In this paper, we present the first large-scale measurement of the deployment characteristics of AS112 using vantage points worldwide. We find that:

- AS112 is dependent on a small number of large operators (§2.1), with one operator serving 41.71% of the vantage points in our study. We identify 469 AS112 sites, run by 97 operators, of which only 57 appear on the self-reported list of operators published by the AS112 project.
- AS112 is connected to at least 235 ASes, and is widely deployed in Europe, North America, and Oceania. However, geographic (§2.2) and network (§2.3) diversity could be improved to increase resilience [50], as only 5% of our vantage points reach an AS112 site in a neighbouring AS.
- Queries sent to AS112 see 23.21% lower response times and 36.11% lower query distances than queries to the root servers, but only 22.24% of vantage points query their closest AS112 site. 31.94% of AS112 queries in our measurements are sent across national borders, compared to 50.88% of root queries (§3).

While prior studies used AS112 to study anycast characteristics [10,29] or analysed AS112 query logs [12,13], ours is, to the best of our knowledge, the first study of AS112 deployment. We conduct large-scale measurements, using 11973 RIPE Atlas probes and 33646 open recursive resolvers, to illustrate the geographical reach and performance of AS112, and compare this unplanned network with the more carefully planned anycast root server deployments. We show that the AS112 network is widely distributed, with better performance than the root servers, but increasing geographical diversity and decreasing its reliance on a small group of operators would improve resilience.

2 Understanding AS112 Deployment

AS112 is a set of anycast DNS servers that capture leaked reverse DNS queries for private and link local addresses [6] and leaked queries for `home.arpa` [45] and `service.arpa` [35]. The `blackhole-1.iana.org` and `blackhole-2.iana.org` nameservers respond to these queries with `NXDOMAIN` [6]. A third nameserver, `prisoner.iana.org`, handles erroneous dynamic updates [6,13]. In addition, DNAME redirection for AS112, introduced in 2015 to redirect arbitrary queries to AS112 [5,49], uses the nameserver `blackhole.as112.arpa`. When deployed following RFC 7534 [6], a single multi-homed server acts as all four nameservers.

Anyone can run an AS112 INSTANCE by announcing the AS112 anycast prefixes via BGP [6]. A SITE [23] contains one or more co-located INSTANCES [29]. An anycast DEPLOYMENT [34,54] is the set of SITES run by one operator.

AS112 nameservers respond to `TXT` queries for `hostname.as112.arpa` and `hostname.as112.net` with information about the location and operator of the SITE (e.g., *'RIPE NCC, Amsterdam, The Netherlands. See* http://www.as112.net/ *for more information.'*) [6]. The format of the responses is not consistent.

To find the geographical locations and operators of AS112 SITES, we use RIPE Atlas to send `TXT` queries for `hostname.as112.arpa` and `hostname.as112.net`

Table 1. The AS112 DNS query datasets (excl. recursive RIPE Atlas queries). Valid answers specify are used in further analysis, invalid answers were not used.

Measurement	Version	VPs	Valid Answer	Invalid Answer			Sites
				No Answer Section	Unknown Location/Operator	GPDNS in NSID	
`hostname.as112.arpa`	IPv4	11540	44270	2221	98	1	310
(RIPE Atlas)	IPv6	3671	12603	568	66	0	120
`hostname.as112.net`	IPv4	11302	44532	2804	224	16	331
(RIPE Atlas)	IPv6	3486	13095	1359	138	0	130
`hostname.as112.arpa` (open resolvers)	IPv4	26267	26267	5495	834	n/a	306
`hostname.as112.net` (open resolvers)	IPv4	26635	26635	5619	701	n/a	326

to `blackhole-1.iana.org`, `blackhole-2.iana.org`, `prisoner.iana.org` and `blackhole.as112.arpa`, in IPv4 and IPv6 (similar to studies [8,29]). These are *non-recursive* queries, sent directly from the probes to the nameservers, allowing us to analyse distances and response times between probes and SITES (§3.1). This also ensures the response will contain any NSID set by the AS112 INSTANCE (NSID is lost in recursive queries [9]). To verify that recursive queries yield similar results, we sent *recursive* `hostname.as112.arpa` and `hostname.as112.net` queries (in IPv4 and IPv6) using 891 randomly distributed RIPE Atlas probes.

Most RIPE Atlas probes are in Europe and North America [47]. To reduce bias, we sent `TXT` queries for `hostname.as112.arpa` and `hostname.as112.net` to 33646 open IPv4 recursive resolvers from a Censys scan [27] (similar to [8,29]), located in 6055 ASes and 18708 BGP prefixes (compared to 3829 ASes for RIPE Atlas). We used *recursive* resolvers, not DNS forwarders, to ensure they queried AS112 directly [51], and only used IPv4 resolvers, as Censys does "not conduct comprehensive IPv6 scans" [28]. The resolvers were probed from one vantage point; multiple vantage points are unlikely to detect more SITES, as the LACeS anycast census [31] only found 14 resolvers be anycast with high confidence.

All measurements were performed in September 2025. Ethical considerations relating to the measurements are discussed in Appendix A. The data gathering and analysis code is available at https://doi.org/10.5281/zenodo.17863954.

We used a semi-automated process to extract SITE locations and operators from the responses. Most responses specified a city, in which case we determined its geographic coordinates using Google, or an airport code, which we geolocated using online information [1]. If the information was ambiguous, we manually searched to determine the location. If no location was given in the `TXT` record, we checked whether the NSID (9.52% of responses) or reverse DNS records of unicast

IP addresses given the `TXT` record (1.87% of responses) encoded a location. SITES were geolocated with city-level granularity.

We excluded responses with no answer section (9.63% of responses), answers with no location or identifying information (1.10%), and answers with `GPDNS` in the NSID (0.01% – they were likely intercepted and sent to the Google Public DNS resolver [44]). For 2.11% of (non-recursive) RIPE Atlas responses and 0.01% of open resolver responses, the geolocation violates speed-of-light constraints (200km/ms), based on the response time. We do *not* exclude these responses, as we cannot tell whether it is due to inaccurate geolocation of the probe or the SITE, and because the bias introduced by these measurements is likely counteracted by geolocation inaccuracies that *decrease* the distance. 11973 RIPE Atlas probes and 30208 resolvers received valid responses that were *not* excluded. Table 1 summarises our datasets. We refer to the RIPE Atlas probes and resolvers collectively as Vantage Points (VPs). Figure 2a shows the locations of the resolvers.

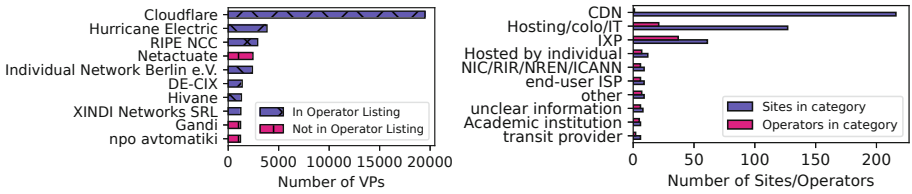
We assume that responses that are identical, except for the strings '`hostname.as112.arpa`' and '`hostname.as112.net`', that come from the same location are from the same SITE. This distinguishes SITES that only encode the location in the NSID. We don't distinguish SITES based on the NSID because some operators use different NSIDs for different INSTANCES in the same SITE.

Some VPs don't consistently query the same SITE. For 31.36% of probes in IPv4 (40.94% IPv6) and 26.83% of resolvers, responses to `hostname.as112.arpa` and `hostname.as112.net` come from, or appear to come from, different SITES, mainly due to inconsistent formatting and variation in internal routing (Appendix B). For 848 IPv4 probes (265 IPv6), queries to the four nameservers reach different SITES due to inconsistent routing and lack of DNAME support (Appendix C).

2.1 AS112 Operators

Sites and Features—Our non-recursive RIPE Atlas measurements found 416 AS112 SITES, of which 405 responded to IPv4 (194 IPv6; 183 both). The recursive open resolver queries found 388 SITES, of which 342 were found by RIPE Atlas. Recursive RIPE Atlas measurements found 7 additional SITES. In total, we found 469 SITES, significantly more than the 72 [8] and 65 [29] SITES found in 2012 and 2013. That the recursive resolvers did not find more SITES than RIPE Atlas indicates that this is close to the true number of SITES. 389 of the 416 SITES found through non-recursive RIPE Atlas measurements respond to queries sent to `blackhole.as112.arpa`, indicating DNAME support. This is a lower bound, as not all SITES received this query (Appendices B, C). We do not consider the recursive RIPE Atlas queries in the following (except in Fig. 2b and Table 2), as we cannot conclusively determine which/how many resolvers queried each SITE, and most of the analysis relies on associating VPs with the SITES they query.

Operators— DNS-OARC maintain an AS112 operator listing [7] based on "*voluntary submissions [...] and ad-hoc surveys*" and detection at IXPs, noting it is likely that some SITES are missing and some inactive. In September 2025,



(a) Top 10 AS112 operators, based on number of VPs whose queries they answered

(b) Categories of AS112 operators

Fig. 1. AS112 Operators

this included 189 operators: 107 manually reported at 135 SITES, and 139 automatically detected IXP SITES run by 96 operators (14 of which were manually reported).

We found 97 operators, of which 40 are not present on the AS112 operator list, including three of the most queried operators (Fig. 1a). Similarly, Fan et al. [29] in 2013 found 64 SITES, of which 35 were not on the published list at that time. Using the `TXT` records and online information (e.g. operators' websites), we categorise the operators (Fig. 1b; note that all "CDN" SITES belong to Cloudflare). 37 IXP operators host SITES, as suggested in [6].

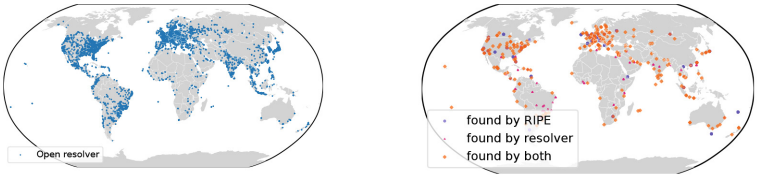
Our measurements did not find 132 of the 189 operators on the published AS112 operator list, possibly because queries are drawn to more well-connected networks (e.g., Cloudflare). However, only 73 of these operators appear to be active: 3 of the 58 operators that listed a transit AS were neighbours of AS112 according to RIPE Stat [48], 69 operators at IXPs peered with AS112, according to PeeringDB [15], and another operator responded to `hostname.as112.arpa` queries on a unicast address listed on the website. We don't consider these operators in the following as we cannot confirm they are reachable by *any* clients.

The discrepancy between the SITES and operators found by us, and those listed by DNS-OARC on the AS112 website is likely because the list relies on manual effort: only SITES at IXPs are detected automatically. DNS-OARC could periodically run measurements to update the list, as discussed in [8], though this would require manual effort to parse and classify the TXT records.

Deployment sizes—AS112 DEPLOYMENTS differ in size. Cloudflare joined in 2022, using the platform of the Cloudflare public resolver [18], greatly increasing the number of SITES [8,29]. It is by far the largest DEPLOYMENT, with 216 discovered SITES, of which at least 177 contain multiple INSTANCES. Other DEPLOYMENTS are smaller, and many don't appear to have load-balanced SITES, as they never return the same answer with different NSIDs. As a result, the number of VPs that query each operator is unbalanced (Fig. 1a): Cloudflare is queried by 41.71% of VPs. The Gini coefficient [30] of the share of VPs that query each operator is 0.78, indicating high inequality. While there are many operators, this inequality is a concern as they contribute on a volunteer basis. The exit of a large operator could shift the load in an unpredictable manner, leading to cascading failure of smaller operators who can't deal with the load.

2.2 Geographic Distribution of AS112 Sites

In a volunteer-based system like AS112, SITES could cluster in regions where the project is well-known, skewing the geographic impact of localised failures. Additionally, AS112 queries originating in regions with low coverage might travel via international links, increasing network load and costs [33]. While AS112 queries are not generally latency sensitive, poorly-written applications may block waiting for the `NXDOMAIN` responses and would benefit from proximity to AS112.



(a) Location of open resolvers (b) Location of the AS112 SITES

Fig. 2. Location of open resolvers and AS112 SITES

Table 2. AS112 SITES per 1M inhabitants

UN Sub-Region	SITES/1M	UN Sub-Region	SITES/1M
Polynesia	3.56	Central Asia	0.11
Melanesia	3.45	Latin America and the Caribbean	0.10
Australia and New Zealand	0.50	Western Asia	0.09
Northern America	0.31	Sub-Saharan Africa	0.05
Western Europe	0.28	South-eastern Asia	0.03
Northern Europe	0.22	Northern Africa	0.02
Southern Europe	0.19	Southern Asia	0.01
Eastern Europe	0.14	Eastern Asia	0.01

AS112 SITES are mainly located in Europe and North America (Fig. 2b). To assess deployment density we count the number of SITES per 1M inhabitants in each UN subregion [4] (Table 2). Population is an imperfect approximation of AS112 demand, but we were unable to access representative AS112 query logs to determine sources of AS112 traffic, and leave this for future work. Apart from high rates in Polynesia and Melanesia (caused by two Cloudflare SITES), Australia/New Zealand, North America and Europe have the highest rates. Other regions would benefit from additional SITES, especially because queries in these regions are often sent across borders (§3.1) suggesting poor locality.

These results could be skewed by the placement of the VPs. The number of VPs in a country and its population [55] is only weakly correlated (Pearson correlation coefficient 0.15 for RIPE Atlas and 0.34 for open resolvers), and the number of SITES found in a country is more strongly correlated with the number of VPs than its population (correlation between population and number of SITES is 0.22 for RIPE Atlas and 0.38 for open resolvers, correlation between number of VPs and SITES is 0.78 for RIPE Atlas and 0.80 for open resolvers). There may be regions with undetected SITES because no VPs are close enough to query them.

RIPE Atlas probe locations may correlate with AS112 SITES because both attract the same type of volunteer operator. The uneven distribution of SITES found by resolvers is partly because some regions received many invalid responses: many resolvers in Africa and India received DNS errors or empty answers and most resolvers in China queried SITES whose answers were discarded because they encode the SITE location in the NSID, which is lost in recursive queries [9].

2.3 Network Distribution of AS112 Sites

Apart from geographical diversity (§2.2), AS112 must be well-connected for resilience and to ensure sensitive queries [14] are resolved locally. We count ASes directly connected to AS112, VPs in neighbouring ASes, and routing inefficiencies.

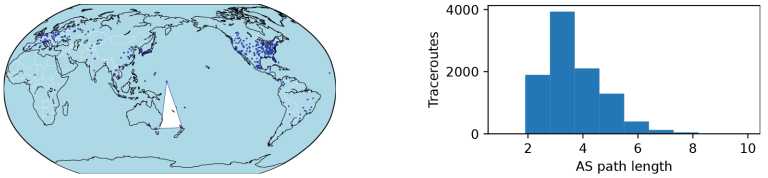
For some SITES, the AS112 website lists *host ASes* (final transit AS on the path to an AS112 SITE). To find more host ASes, we traceroute to `blackhole-1.iana.org`, using RIPE Atlas probes that only reached one SITE when querying `blackhole-1.iana.org`, to ensure traceroutes go to the same SITE. The host AS is the AS of the hop before `blackhole-1.iana.org`, determined by RIPE Stat.

We found 235 host ASes for 337 SITES: the website gave 33 host ASes for 289 SITES, and the traceroutes found 204 host ASes for another 48 SITES. For 37 of the 50 SITES for which we found a host AS using both methods, the host ASes were different; in this case we used the host AS given on the AS112 website. A total of 13.35% of SITES have several host ASes, with one DE-CIX SITE having 72 host ASes. CLOUDFLARENET hosts the most SITES (216), followed by MISAKA-ANYCAST (24 SITES). Most SITES aren't directly accessible to clients within their own AS: of the 36194 VPs that query a SITE with a known host AS, only 8.47% are in the host AS of any SITE, and only 5% also query that SITE.

The median SITE is queried from VPs in 8.0 ASes, but some SITES are queried from hundreds of ASes (Table 3). A log-log complementary cumulative distribution plot, omitted due to space constraints, is suggestive of a heavy-tailed popularity distribution but available data is insufficient to confirm [26].

To measure geographic spread of the VPs querying SITES and the extent queries come from widely distributed networks, we consider the *convex hull*. For the 80.52% of SITES queried from >2 locations we project VP coordinates onto an Azimuthal Equidistant Projection, centred on their mean coordinate, determine

which VPs bound their convex hull, and calculate the area of the hull on the globe (Appendix D). While the hull area could be skewed by outlier VPs, we don't know the true distribution of clients in the hull, so we use it to approximate client spread. Most convex hulls are small, with a median area similar to Germany [55]. The smallest hull is $0.08km^2$; the largest, for a Hurricane Electric SITE, covers 98.78% of Earth [41] (Fig. 3a). The SITES that are queried by the most ASes have large hulls (Table 3), which is indicative of routing inefficiency, and possible anycast polarisation [43]. These SITES draw in many clients (correlation between hull size and number of VPs querying a SITE is 0.77), diverting them from more local AS112 SITES, leading to instability if the large AS112 SITE fails. Large hulls don't appear to increase response time: convex hull area and average response time (measured by RIPE Atlas) per SITE are only weakly correlated (Pearson correlation coefficient 0.46). However, SITES with large hulls are in areas with many VPs, so many VPs in the hull are close to the SITE (Table 3), and the number of clients on the geographic periphery of the hull may be larger.



(a) Largest convex hull (shaded) (b) AS Path Length Distribution

Fig. 3. Largest convex hull and AS path length distribution

Table 3. Top 10 SITES, by number of VP ASes

Operator & Country	ASes	Hull (km^2)	% Earth	Distance (km)		
				Mean	Median	90%-ile
Hurricane Electric, US	872	503.75M	98.78	6274.44	4138.50	11822.00
Hurricane Electric, US	713	503.75M	98.77	6077.09	4084.00	11822.00
RIPE NCC, NL	635	383.44M	75.18	2066.38	649.00	8578.00
Hurricane Electric, US	439	192.86M	37.82	4955.63	6174.00	7540.90
Hurricane Electric, US	435	192.86M	37.82	4953.53	6180.50	7542.80
Individual Network Berlin e.V., DE	410	323.90M	63.51	1518.59	538.00	3342.00
DE-CIX, DE	317	261.62M	51.30	1632.32	198.00	8734.00
npo avtomatiki, RU	303	300.64M	58.95	3806.39	1787.00	9399.00
npo avtomatiki, RU	293	304.60M	59.73	3947.63	1790.00	9399.00
Hivane, FR	293	310.89M	60.96	2791.67	462.00	9647.00

Finally, we consider the AS path length. Using RIPE Stat, we determine the AS of each traceroute hop, counting repeated ASes as one (i.e., B B * C * C → B * C with path length 3). The average length is 3.48 ASes, but some paths are noticeably longer (Fig. 3b); those ASes could benefit from AS112 deployment.

3 Comparing AS112 and the Root

The DNS root servers are run by 12 independent organisations, some of which (e.g. K-root [2] and F-root [32]) allow volunteers to apply to run a SITE. However, while the placement of some DNS root servers is known to be sub-optimal [34], it is more coordinated than the placement of AS112 SITES, which are run by an unlimited number of organisations that might not be aware of each other. In the following, we compare the placement of AS112 SITES and the 13 DNS root server DEPLOYMENTS, considering distance, response time, amount of queries sent across borders (§3.1), and distance inflation (§3.2). While AS112 mainly diverts queries from the `in-addr.arpa` servers, it also prevents queries for `home.arpa` and `service.arpa` from reaching the `arpa` nameservers, which are currently served by 12 of the 13 root letters (note that initial queries will still reach the root/`arpa` servers to retrieve the parent NS records, but subsequent queries will only go to AS112). Additionally, comparing AS112 to the more carefully planned root provides an insight into the effectiveness of unplanned anycast deployments.

Table 4. Number of queries and SITES in the root dataset

	Probes	Answers	SITES	A	B	C	D	E	F	G	H	I	J	K	**L**	M
IPv4	10274	133562	1076	27	6	12	164	225	239	6	12	77	101	100	88	19
IPv6	3345	43485	740	25	6	12	106	146	145	5	12	57	84	74	55	13

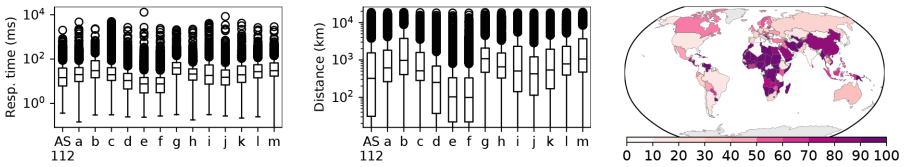
Every four minutes, RIPE Atlas probes send `CHAOS TXT hostname.bind` queries directly to the 13 root servers [46]. Root server operators encode the SITE location in their responses using airport codes (e.g., `c01.prg.eroot` for a E-root SITE in Prague) or a custom mapping [3,53], enabling us to geolocate the SITE.

We consider IPv4 and IPv6 `hostname.bind` queries to the root servers sent in the same hour as RIPE Atlas `hostname.as112.arpa` queries, from probes that sent `hostname.as112.arpa` or `hostname.as112.net` queries in the same address family (one response per address family, probe and root letter, excluding probes receiving errors or abnormal responses [44]). We assume responses from the same root letter encoding the same location come from the same SITE. As in §2, we do not exclude the 0.70% of root responses whose geolocation violates speed-of-light constraints. Table 4 summarises the root dataset.

3.1 Distance, Response Time, and Geographic Reach

Root server deployments are planned but may be resource constrained, AS112 deployment is uncoordinated but potentially larger in scope. We compare the distance and response time from our VPs to the AS112 and root SITES. Distance, also considered in similar studies [17,36,38,50], gives a lower bound on latency (due to the speed of light [50]) and shows how the VPs are distributed relative to the SITES. AS112 queries are not generally latency sensitive, but comparing response times lets us compare the real-world performance of AS112 to the root.

We count each {VP, SITE} pair once, and only use response times from RIPE Atlas (open resolver response times are inflated since they include the path from the measurement host to the resolver). Most probes sent multiple queries to the same SITE (§2), and we take the average of those response times.



(a) Response Times (b) Distances (c) Cross border AS112

Fig. 4. Distances, response time, and country boundaries

AS112 has *lower* median response times and distances than the root servers. The median response time to the root is 18.66ms, for AS112 it is 14.33ms (23.21% lower). The median distance between RIPE Atlas probes and the root is 504.0km, the median distance between VPs and AS112 is 322.0km (36.11% difference). Response times (Fig. 4a) and distances (Fig. 4b) vary between root letters: F and E-root have lower median response time (7.57ms, 7.58ms) and distance (100.00km, 101.00km) than AS112. The better AS112 performance is partly due to the prevalence of Cloudflare; non-Cloudflare SITES have lower median response time (16.73ms) but higher median distance (684.00km) than the root. As of 2023, 76% of F-root SITES are hosted by Cloudflare [11], which explains its performance. Still, this shows that uncoordinated deployment *at scale* performs well.

Queries that leak to AS112 may contain sensitive device names or configuration details [14]. Failing to handle these locally, particularly sending them across borders, could present a privacy issue. We find 31.94% of AS112 queries were sent across borders, compared to 50.88% of root queries, showing AS112 is more effective at handling queries locally. However, AS112 has more SITES than F-root (the largest root letter we found), and only 12.20% of F-root queries cross borders, so the number of AS112 queries crossing borders is high. Queries cross borders more in areas with low coverage (Fig. 4c, §2.2), though this may be skewed by low data availability in, e.g., China (§2.2). These areas could benefit from more AS112

SITES, particularly as only 28.24% of queries that cross borders are answered in a neighbouring country (only 31.33% in the same UN subregion).

3.2 Distance Inflation

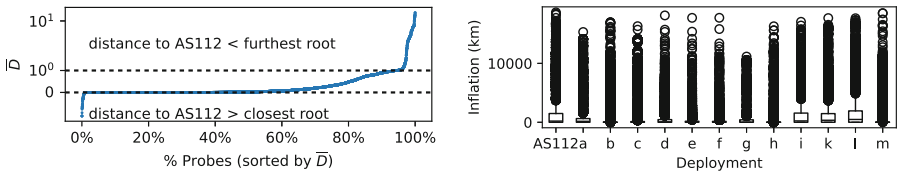
To determine how well-placed the AS112 and root SITES are relative to each probe, we consider the distances between each RIPE Atlas probe and the AS112 and root SITES it queries. We define the *Normalised Distance Score* ($\overline{D}$) as:

$$\overline{D} = \frac{(D_{\text{AS112}} - D_{\text{Root}\Downarrow})}{(D_{\text{Root}\Uparrow} - D_{\text{Root}\Downarrow})} \tag{1}$$

where D_{AS112} is the distance to the furthest AS112 SITE queried by the probe, and $D_{\text{root}\Uparrow}$ and $D_{\text{root}\Downarrow}$ are the distance to the furthest and closest queried root SITE. This sets the distance to the closest and furthest root to 0 and 1, and maps the distance to AS112 into that interval. We consider the furthest AS112 SITE as 60.04% of probes only queried one SITE, for the others this is the maximum $\overline{D}$.

Most AS112 SITES are well placed: for 22.65% of probes, the distance to AS112 is less than, or equal to, the minimum distance to the root, while for another 71.71%, it is not more than the distance to the furthest root SITE (Fig. 5a). Many cases where AS112 is further away than any root server ($\overline{D} > 1$) occur when routing to AS112 doesn't choose the closest SITE. If the probes with $\overline{D} > 1$ queried the closest AS112 SITE, they would have an average $\overline{D}$ of -0.05.

We define *distance inflation* as the difference between the distance to the SITE queried by a VP and the closest SITE (similar to [38,50]). Unlike [10,23,34,36,37,50], we consider distance and not latency inflation: measuring latency inflation requires the unicast addresses of the SITES (to measure the latencies to specific SITES), which are not always known. AS112 has a median distance inflation of 199km, for the root it varies [34,36,38] from 474km (L-root) to 0km (B, C, E, F, G, H, and M-root) (Fig. 5b). The distance to AS112 could be decreased: only 22.24% of VPs query the closest AS112 SITE, compared to 30.37% for L-Root and 83.60% for B-Root. If every VP queried the closest AS112 SITE, the median *distance* would be 23.00km. Despite the more systematic deployment of the root, 12.33% of RIPE Atlas probes are closer to an AS112 SITE than to any root SITE.



(a) Normalised Distance Score for all probes (b) Distance inflation for AS112 and root

Fig. 5. Normalised Distance Score and distance inflation

Smaller anycast networks often have lower distance inflation because queries are less likely to go to suboptimal SITES [23,34,36,50]; AS112 might have higher distance inflation because it has more SITES (469) than any root letter (Table 4). Inflation also varies between AS112 operators: for 15.46% there is no distance inflation; 20.62% of operators have mean distance inflation > 1000km. Thus, while AS112 SITES are well placed, compared to the root, providing access to the geographically closest SITE would further decrease distances.

4 Related Work

Fan et al. [29] compared `CHAOS TXT` query accuracy (§3) with `hostname.as112.arpa`, while Ballini et al. [10] compared anycast characteristics of F-root, J-root and AS112. Unlike our work, these studies don't consider AS112 deployment characteristics such as operators and location. Others studied dynamic updates sent to AS112 [12,13], or sensitive information in AS112 queries [14]. An informal measurement by the AS112 project in 2012 also counted the number of SITES[8].

Anycast characteristics of root servers, e.g., catchments [38], latency [23,37,50], stability [50,54] and inflation [34,36,50], are frequently studied. Other targets include CDNs [17,34,40], cloud providers [42], TLD servers [37,50] and public resolvers [25]. Like our work, [16] studies client and server locations, but for a non-anycast CDN. We use DNS queries to find SITES, other anycast measurements use ping [19–21], TCP logs [43], or use SITES as measurement hosts [24,52].

5 Conclusions

We studied the deployment of AS112, finding 469 SITES, significantly more than past studies [8,29]. While these SITES are run by 97 operators (§2.1), one operator is queried by 41.71% of VPs. The median distance that AS112 queries travel is 36.11% lower than root queries, with 23.21% lower response times (§3.1). Still, geographic and network diversity could be improved: AS112 is mainly deployed in Europe, North America and Oceania, only 8.47% of VPs are in an AS that is connected to AS112, and 31.94% of AS112 queries are sent to different countries. Future work will study differences in IPv4 and IPv6 AS112 queries; determine the quantity and source of AS112 queries (similar to [12,13]), and query privacy.

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A Ethical Considerations

We use the RIPE Atlas measurement platform to collect DNS responses from, and latency measurements to, publicly available servers. In some cases the information in the `TXT` records returned in response to queries for `hostname.as112.arpa` and `hostname.as112.net` contains personal information (e.g., the name of a contact person for the SITE). While this data has been made publicly available by the SITE operator, we treat it as confidential.

We also make queries to a list of open recursive resolvers, derived from a Censys scan [27]. While these queries were made without prior approval from the resolver operator, we minimised any potential impact that the additional traffic might have. Queries were strictly rate-limited, to one query per second, and were spread evenly over time to avoid traffic spikes. The additional traffic that our study has generated toward these open resolvers is negligible, and we do not expect it to have any operational impact.

Advice was sought about this study from our institution's research ethics committee, who stated that approval was not required.

B Comparing `.arpa` and `.net` Responses

As discussed in §2, 3487 probes in IPv4 (1373 IPv6) received different responses for `hostname.as112.arpa` and `hostname.as112.net` queries to the same nameserver. 10182/12546 such IPv4 responses (3726/4389 IPv6) encode the same operator and location, with formatting differences. Another 1264 IPv4 responses (393 IPv6) come from the same operator in a different location, or a related operator (i.e., NIX.CZ and NIX.SK), possibly due internal routing decisions.

To determine whether the remaining 1100 IPv4 queries (270 IPv6) go to different SITES due to anycast flaps, we re-ran the IPv4 `hostname.as112.arpa` and `hostname.as112.net` queries on the 479 probes in this set, twice, ∼90min apart. Of the 427 probes that participated, 310 no longer received inconsistent responses from the nameservers that previously gave inconsistent results (for 64 probes the result differs depending on the nameserver). Here the difference could be caused by anycast flaps or unstable routing. We leave explaining why the remaining 53 probes consistently received different responses for future work.

C Nameserver Impact on AS112 Site Choice

Queries to `blackhole-1,2.iana.org`, `prisoner.iana.org` and `blackhole.as112.arpa` are mostly routed to the same SITE (94.40% for IPv4 and 93.27% for IPv6 queries, see §2). Of the probes whose queries for `hostname.as112.arpa` reach multiple SITES in IPv4, 85.92% reach SITES run by different operators (96.95% in IPv6), indicating the query is not being load balanced between SITES run by the same operator. Rather, the cause seems to be a lack of DNAME adoption, anycast flaps/routing instability, or differing BGP announcements.

Note that this section only considers `hostname.as112.arpa` queries, sent by probes that successfully queried all four nameservers.

DNAME adoption— 69 IPv4 probes (16 IPv6) reach the same SITE when querying `blackhole-1.iana.org`, `blackhole-2.iana.org` and `prisoner.iana.org` (the *direct delegation nameservers*), but a different SITE when querying `blackhole.as112.arpa`, because the SITE they query for the direct delegation nameservers doesn't support DNAME [5]. If a SITE doesn't announce the prefix for `blackhole.as112.arpa`, then these queries will go to a different SITE. We assume a SITE supports DNAME if it responds to `hostname.as112.arpa` or `hostname.as112.net` queries sent to `blackhole.as112.arpa`, in IPv4 or IPv6.

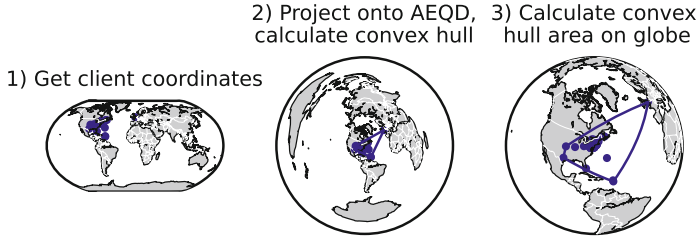


Fig. 6. Process to calculate the convex hull area.

Anycast flaps—The remaining 499 IPv4 probes (115 IPv6) queried at least one DNAME SITE when querying direct delegation nameservers. To determine if they query multiple SITES due to anycast flaps or routing instability, we repeat the IPv4 and IPv6 `hostname.as112.arpa` measurements for these probes after 1-3 days. 492 IPv4 and 115 IPv6 probes participated in these measurements. In IPv4, 63 probes no longer queried multiple SITES (11 in IPv6). Of the 429 IPv4 probes that still queried multiple SITES, 295 queried a different set of SITES than before (44 of 104 probes in IPv6). Thus, for 358 probes in IPv4 and 55 probes in IPv6, the difference is likely due to anycast flaps or other routing instability.

BGP Announcements— Some probes consistently queried one SITE for the direct delegation nameservers and another for `blackhole.as112.arpa`, but not due to DNAME or anycast flaps. The direct delegation nameservers use a different anycast prefix than `blackhole.as112.arpa`, so the probes' ASes might receive the announcements for the two prefixes from different ASes. We run traceroutes to all four nameservers, using 52 IPv4 probes (51 IPv6) that fit this category. We determine the last AS before AS112 (final AS for unsuccessful traceroutes) using RIPE Stat [48]. For 41/52 IPv4 probes (17/51 IPv6), this AS is the same in paths to the direct delegation nameservers, but different for `blackhole.as112.arpa`, suggesting the prefix for `blackhole.as112.arpa` is announced by a different AS.

D Convex Hull Calculation

As shown in Fig. 6, to determine the convex hull (§2.3) we project the VP coordinates onto an Azimuthal Equidistant Projection, centred on their mean coordinate, determine which VPs bound the convex hull, and calculate the area of the hull on Earth (modelling Earth as a perfect sphere).

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